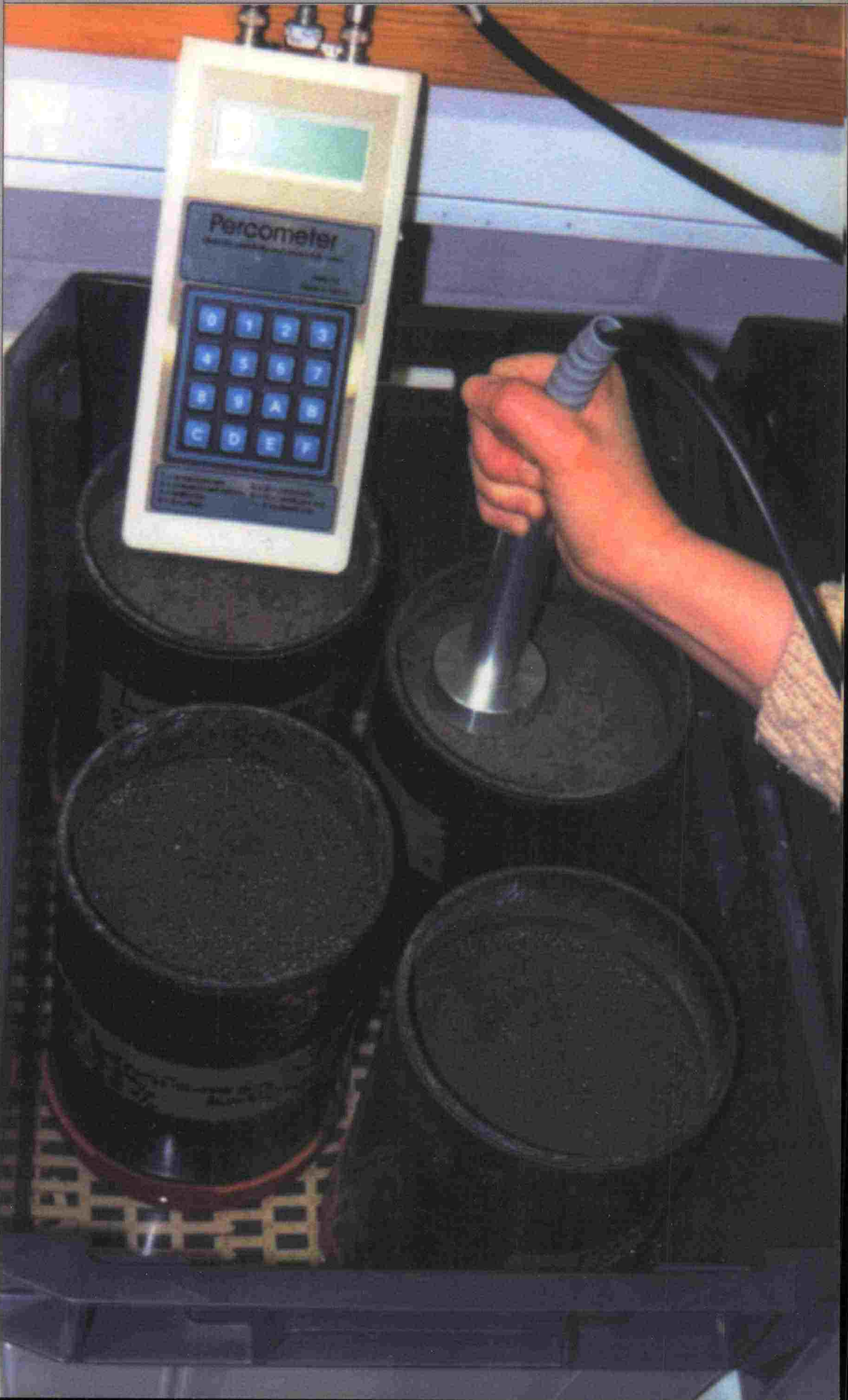
Timo Saarenketo

TUBE SUCTION TEST - RESULTS OF ROUND ROBIN TESTS ON UNBOUND AGGREGATES

Finnish National Road Administration



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SUMMARY

The Tube Suction Test (TST) has been developed to investigate the moisture susceptibility of unbound base course aggregates and has also been successfully applied in the research of bound aggregates. During the TST, the sample is compacted into a plastic tube, dried, and placed in a bath containing 10-20 mm of water. The amount of unbound water absorbed by the sample is then assessed using the dielectric value of its surface. Based on the results of the test, the samples can be divided into three qualitative categories: good, marginal, and poor.

This study, which is the result of co-operation between the Lapland Road Region of the Finnish National Road Administration (Finnra), the Texas Transportation Institute (TTI) and the Office of Minnesota Road Research (Mn/ROAD), compares TST results taken from the laboratories of the cooperating institutes. Each laboratory studied both good quality and poor quality base course aggregates selected from sites in Finland, Texas and Minnesota in the United States and Saskatchewan in Canada. The classification of these aggregates were determined from their field performance.

The results of the study indicate that despite some disparities, mainly due to sample preparation, the correlation between the test results of each laboratory was positive, with good quality samples proving to be good and problematic samples bad. This report presents the current sample preparation and evaluation methods and suggests improvements for further standardisation of test procedures.

FOREWORD

In 1994-95, Timo Saarenketo and Tom Scullion developed the Tube Suction test (TST) at the Texas Transportation Institute (TTI) for investigating the moisture susceptibility of base course materials. It has proved to be an excellent tool for distinguishing between problematic and good performing base course aggregates.

So far the test has been used by laboratories at the Road District of Lapland, TTI, and the Office of Minnesota Road Research (Mn/ROAD) for the study of large numbers of different unbound and bound aggregates. Based on the results, the aggregates have been divided into three categories: good, marginal, and poor. In the future the TST will be used for the classification and even rejection of aggregates. For this reason studies on the standardisation of the test procedure must be undertaken. During the first stage the laboratories agreed to conduct a so-called "round robin" test. In this test the same aggregate materials were studied using preparation and measuring techniques in use in each laboratory. The aim of the test was to investigate the possible effects of molding and measuring techniques on final TST results.

This research is the result of co-operation between the Lapland Road Region of the Finnish National Road Administration, TTI, and Mn/ROAD. The University of Saskatchewan joined later and sent samples for the other laboratories to test, but did not test the samples sent from the other partner laboratories. Coordination of the test was carried out by Timo Saarenketo (Finnra, Roadscanners Oy), Tom Scullion (TTI), and Dave van Deusen (Mn/ROAD). Seppo Ylitapio (Finnra), Spencer Guthrie (TTI), and Dave Baker (Mn/ROAD) were responsible for the actual labratory tests.

CONTENTS

1. INTRODUCTION

When the ground penetrating radar (GPR) survey technique of roads became increasingly common during the late 1980s and early 1990s, it gave rise to the need for a more accurate understanding of the behavior of the GPR signal in different road structures. The main reason for this is that the travel time of a GPR signal in a given medium is controlled by the dielectric properties of that medium, which in turn are found to reflect the volumetric water content of the soil or aggregate.

In 1994-95, a research project was carried out at TTI, which aimed to clarify the relationship between the electrical and mechanical properties of unbound base course aggregates. This research, funded by the Texas Department of Transportation and the Lapland Road Region, focused on the electrical and mechanical properties of good quality and poorly performing base course aggregates (Saarenketo and Scullion 1996, Scullion and Saarenketo 1997). In connection with this project, Timo Saarenketo and Tom Scullion developed the TST as a special test for unbound base aggregates. The goal of this test was to measure in a passive way the potential for capillary action in an aggregate sample given free access to water by measuring the unbound water content of the sample surface, using a capacitance-based dielectric probe. This free water was found to be a better indicator of mechanical performance of the material than the traditional gravimetric water content (Saarenketo 1995, Saarenketo et al 1998).

The TST immediately proved to be an excellent tool for separating poor performers from good quality unbound aggregates. In 1994-95 in the TTI laboratory, the test was also applied to the research of chemically stabilized base course samples. It was observed that in all the poorly performing base course samples the water migrated upward through the sample raising its dielectric value, whereas samples which had performed well in the field moistened only slightly during the TST. The ingress of moisture into stabilized materials was found to initiate secondary reactions and leaching of the stabilized agent. The end result was rapid and dramatic loss of layer strength and very poor pavement performance.

The development of the system was continued during 1996-97 and 1999 by TTI, as well as in the laboratory of the Lapland Road Region. The Finnra laboratory tested, among other things, the effect of fines (< 0.063 mm) content on the TST results (Ylitapio 1997). Results showed that increasing the fines content also increased the dielectric value of the sample tested. Chemical analysis carried out at the University of Oulu, using the same samples (Yli-heikkilä 1998), also revealed a correlation between the chemical properties and the moisture balance of the materials. These two tests demonstrated that the TST measures the total suction value of the material, which is a function of matric suction (fines content) and osmotic suction (chemical properties).

In 1997 in the Tampere University of Technology started a new project to survey the resilient deformation response of base aggregates before and after they were allowed to adsorb water. The tests were performed using the large scale cyclic loading triaxial test facility in the Geotechnical Engineering Laboratory

(Saarenketo, Scullion and Kolisoja 1998). The results showed that the resilient modulus of the base material in moist conditions was more than 25 % lower than the modulus measured when the material was dry.

At TTI during 1996-97, several good and poor performing aggregates were successfully analysed and classified on the basis of the TST. The effect of different additives on the materials' performance in the TST was also studied.

The goal of this Round Robin Testing Project was to compare the sample preparations, measurement techniques and other issues which affect TST results conducted with the same aggregate samples in each laboratory. The final goal was to improve TST instructions to gain uniform results.

2. TUBE SUCTION TEST PRACTICE

The TST protocol used in the round robin test is presented as follows:

1. About 8000-9000 g of < 18 mm (< 25 mm in TTI) material at its optimum moisture content is compacted into a 150-mm diameter and 180- to 200-mm height plastic tube. As shown in Figure 1, this tube has a series of small (2 mm) holes drilled in the bottom or in the sides about 10 mm from the bottom (see also Figure 4). Compaction was carried out using the sample preparation technique individual for each country (Figures 2 and 3). If the sample surface remained rough, it was evened out using < 2 mm aggregate.

Figure 1. TST tube used in Finland. The plastic cap enables the use of gyratory compactor for sample preparation. The diameter of the holes is 2mm.

Figure 2. ICT gyratory compactor used for the sample preparation in Finland.

When samples bound by bitumen, cement, or other binding substances are tested, the sample height is 100 mm. The sample is dried at +40°C until there is no further significant change in the weight of the sample, typically 3-4 days.

Figure 3. The ICT gyratory compactor has a special mold cell where the TST tube can be placed during the compaction.

2. The dielectric value and electrical conductivity of the sample surface are measured, and the sample is then placed in a plastic bath holding about 10 mm of distilled or deionized water (Figure 4). The sample tube can be covered with a rubber lid to prevent splashes landing on the surface of the sample.

4. TST tubes placed in a water bath in TTI surveys. In Texas the holes are drilled on the sides of the tube about 10 mm from the bottom.

Bitumen bound samples should be cured for 2 days at room temperature prior to the test. Chemically bound samples must be allowed to cure a minimum of 7 days in open air before the test.

3. The dielectric value and electric conductivity are measured on the surface of the sample (Figure 5) at specific time increments, and the sample is weighed in order to allow the moisture content to be determined later. The total time required for the measurements is 10 to 14 days. The dielectric measurements are made using a capacitance-based dielectric surface probe. The current probe manufactured by Adek Ltd in Estonia has a head diameter of 50 mm, and a measuring frequency of 50 MHz. A total of 4 to 6 measurements are recommended from different locations on the sample surface, and the final result is the mean value after the deduction of the greatest and lowest values.

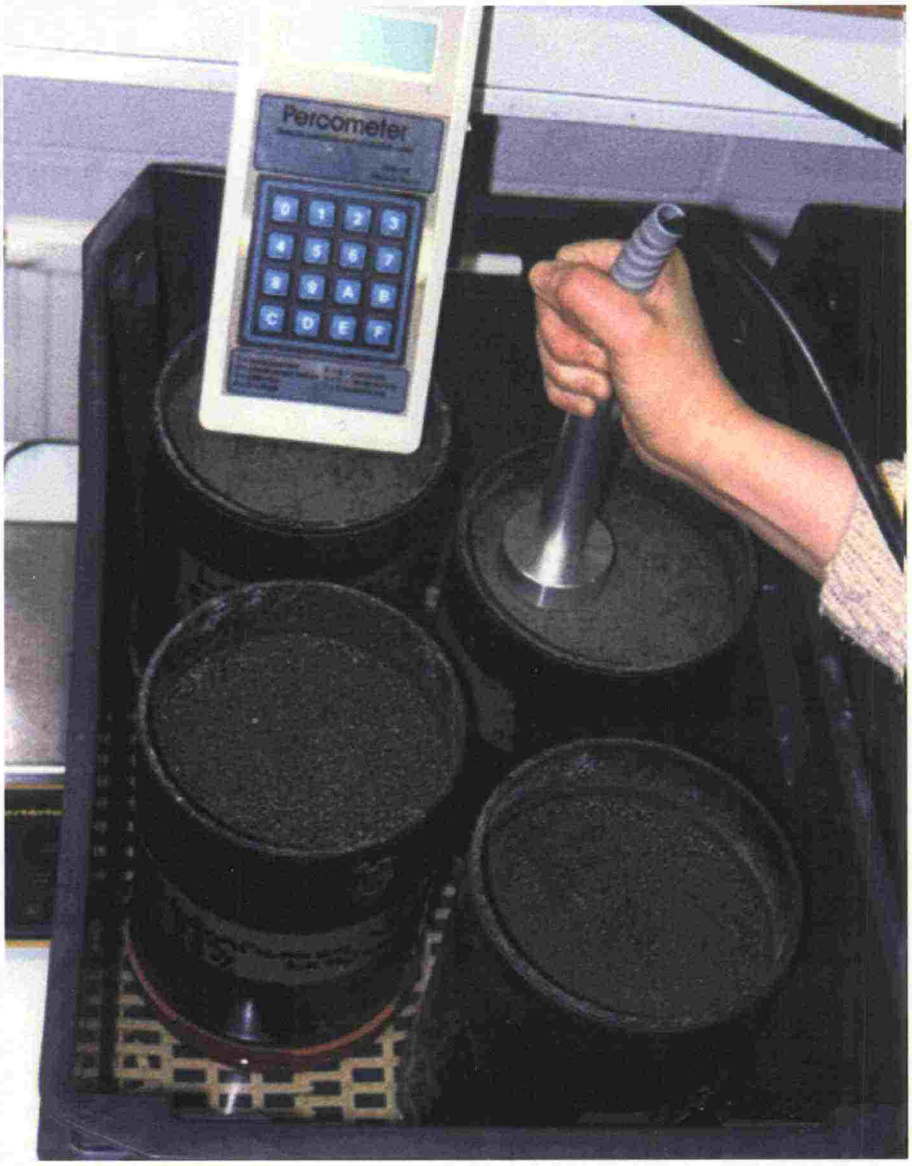

Figure 5. Performing dielectric and electrical conductivity measurements with Percometer surface probe in Finnra laboratory. TST tubes are placed in water bath on a plastic carpet to allow water flow through the bottom holes.

4. At the end of the test, the sample is removed from the plastic tube, dried at +105°C, and weighed to facilitate calculation of the gravimetric moisture content. With the measured height of the sample, it is then possible to calculate the volume and the dry density of the sample.

5. A time-dielectric value graph is produced from the study results, where the asymptotic dielectric value at the end of the TST is used for the aggregate classification. The electrical conductivity results indicate whether the suction value is due to high fines content, in other words matric suction, or whether it is a matter of osmotic suction due to the material's chemical properties. The hydrophobic and hydrophilic properties and water permeability of the substance can also be deducted from the rate at which the dielectric values increase.

6. The classification of the aggregates is the following:

TST-value	**Classification**
< 10	good quality aggregate
10 - 16	marginal (questionable) quality
> 16	poor quality

In Finland the TST value of 9 has also been used as limiting value of good quality aggregate.

3. RESULTS

3.1. SAMPLE PREPARATION COMPACTION, AND DRY DENSITIES

Although the TST itself was performed in essentially the same way at each round robin test location there were differences between the preparation methods of the laboratories, in particular with regard to sample compaction.

The sample preparation method and the execution of the test in Finland has been illustrated in Appendix 1, while Appendix 2 focuses on the preparation methods and the essential results of the round robin test at the TTI laboratory in Texas.

In Minnesota the samples from Texas, Finland, and Saskatchewan were compacted using a 4,54 kg drop hammer while Mn/ROAD materials were compacted using a vibratory method. Curing time was 6 days in 60°C and later 10 days in 40°C. During testing the samples were uncovered, although Minnesota has since begun using covers in the TST. In the first round, the "soft" mode of the Percometer was used in the measurements, which explains the slightly lower values measured in the Minnesota laboratory.

The dry densities of the TST samples molded at each test laboratory are presented in Table 1. Figure 6 compares the dry densities measured in Finland with those measured in Minnesota and Texas. Results show that the gyratory compaction method used in Finland gave higher densities compared with the Minnesota and Texas compaction method, especially in the dry density range around 2.1 g/cm³.

Table 1. Dry densities of the TST samples

	Density (g/cm³)		
Sample	Finland	Minnesota	Texas
Texas Bad Base	1.74	1.58	
Texas Good Base	2.11	2.11	1.97
Minnesota Class 3 (Bad)	2.15	1.88	1.87
Minnesota Class 6 (Good)	2.10	1.91	1.74
Finland Good Base	2.09	1.98	1.98
Finland Bad Base	1.96	2.02	2.04
Saskatchewan Good Base	2.27		2.27
Saskatchewan Bad Base	2.26		2.23

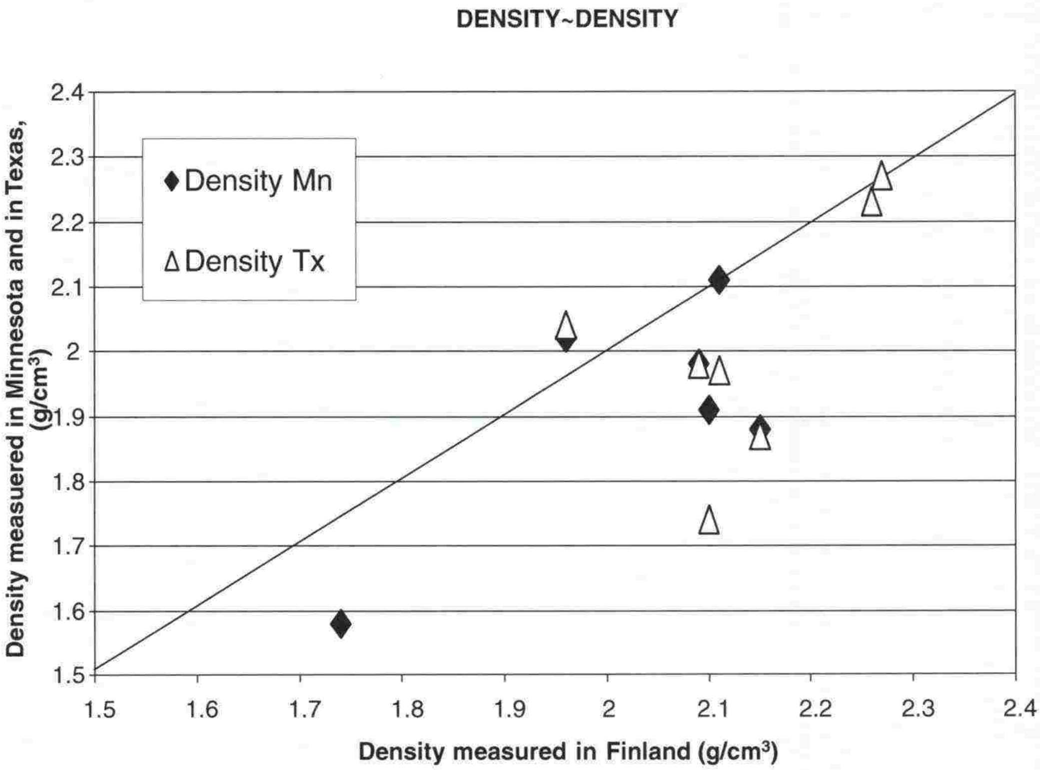

Figure 6. Correlation of the dry densities between Texas and Minnesota samples and the samples studied in Finland

3.2. DIELECTRIC PROFILES

The graphs of the dielectric value versus time for the tested materials are presented as follows:

Texas Bad Quality Base
The round robin TST results for the Texas poor quality base course aggregate are presented in Figure 7. High variability in the final dielectric value of the material was observed in the TST results from each laboratory. The Minnesota laboratory managed to dry the sample well, when the Texas starting values were close to 10. In the Finnish laboratory, the dielectric value rose very quickly to the level of 36-39, but in Minnesota and Texas dielectric values rose more slowly, peaking at a level of 25-27.

Texas Good Quality Base
Figure 8 presents results of the Texas good quality base test. This material gave the most varied round robin test results. Results from the Texas laboratories for the good quality aggregate were even worse than the results of the poor quality aggregate. This is probably due to the fact that the aggregate analysed in Texas was from a different stockpile than the samples sent to Finland and Minnesota. The final results from both Finland and Minnesota indicate the quality of the aggregate to be poorer than estimated. The dielectric values of both were above 15.

Minnesota Bad Quality Base
The results of the TST for the Minnesota poor quality class 3 base are presented in Figure 9. The test results of this sample are fairly consistent between the different laboratories. Only in Minnesota did the dielectric values remain just under 16.

Minnesota Good Quality Base
The class 6 aggregate represents good quality base material in Minnesota and results of the round robin tests are presented in Figure 10. In these measurements the results from the Finnish laboratory are clearly greater than those from Minnesota or Texas. The higher results can be explained by the significantly higher dry density (2.10 g/cm^3) of Finland's sample compared with those from Minnesota (1.91 g/cm^3) and Texas (1.74 g/cm^3) (see Table 1.). However, the results for all the tests indicated the aggregate base to be of good quality.

Finland Bad Quality Base
Results of testing on the Finnish poor quality base are presented in Figure 11. The study results were consistent in the early phase of the test, but after one day Minnesota's results remained at 15 and Finland's results remained at 20, while Texas results continued to rise. In any case, all tests indicated the quality of the base to be very poor.

Finland Good Quality Base
Tohmovaara aggregate represents the Finnish good quality base. Results of the TST are presented in Figure 12. During the first few days of the test results from Finland and Texas were consistent, while in Minnesota tests the values

rose very slowly. Towards the end of the test no great changes in the dielectric values from Finland and Minnesota were observed; the final dielectric values were clearly less than the maximum allowable value of 10 for good quality aggregate. The Texas results were more varied, and the final value rose to just above 10. The higher Texas value is probably due to the excessive use of fine-grained material for smoothing rough sample surfaces.

Saskatchewan Bad Quality Base

Figure 13 presents the results of the Saskatchewan poor quality base. Dielectric profiles showed that while in the Finnish laboratory the dielectric value raised within three days to a level of more than 15, the corresponding values in Texas and Minnesota remained at the starting level for more than two days before slowly beginning to rise. According to the test results, the Saskatchewan poor quality base would be ranked in both Texas and Minnesota as a marginal base and in Finland as bad quality base.

Saskatchewan Good Quality Base

The results of the Saskatchewan good quality base tests are presented in Figure 14. According to the results, the base behaved almost identically in the Minnesota and Texas laboratories. In Finland the dielectric values rose higher at the beginning, but returned later to the same level as the Minnesota and Texas results. It is worth noting that Texas laboratory results gave almost similar results for both good and poor quality base materials which were 11.0 and 10.1 represently.

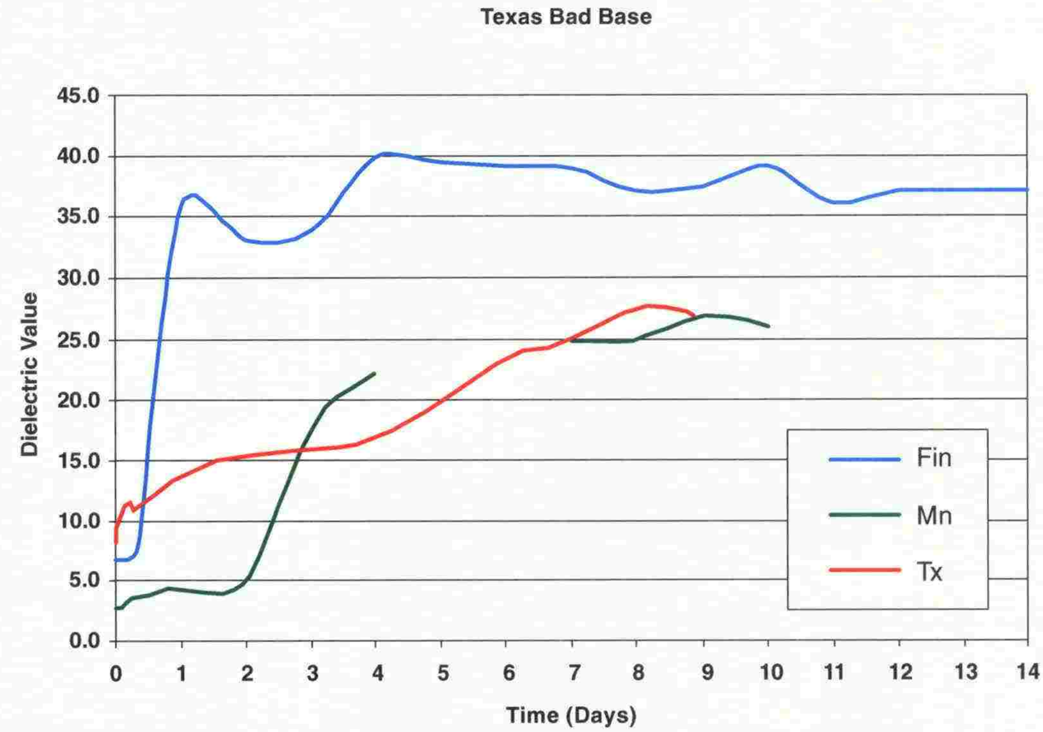

Figure 7. Tube Suction test dielectric profiles from Texas bad quality base material

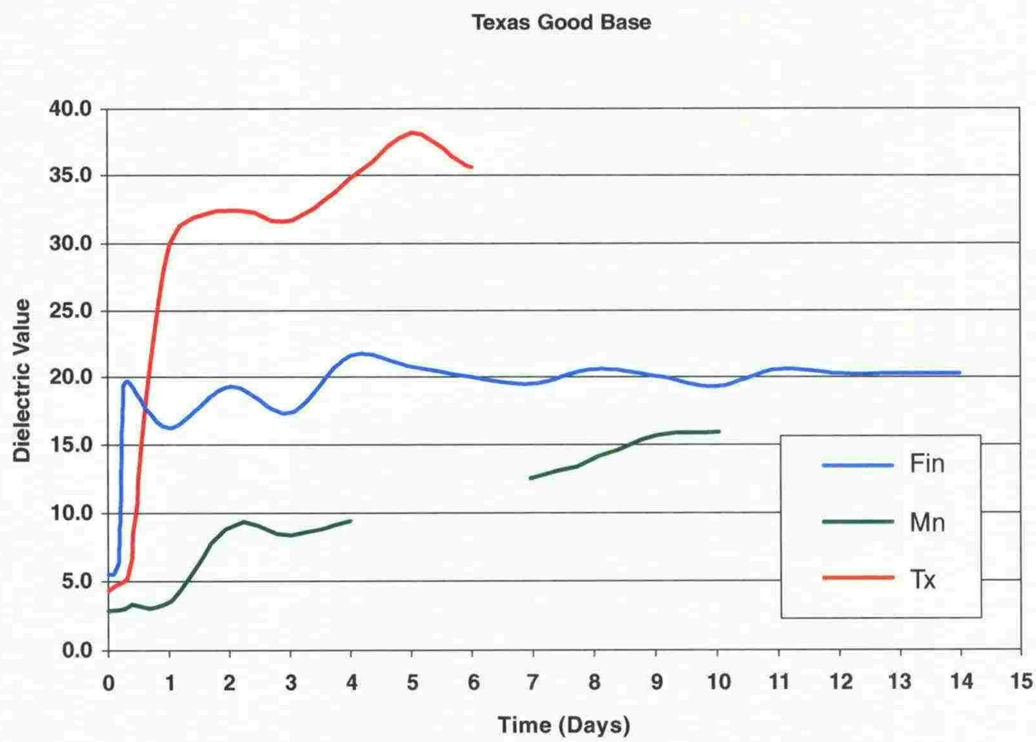

Figure 8. Tube Suction test dielectric profiles from Texas good quality base material

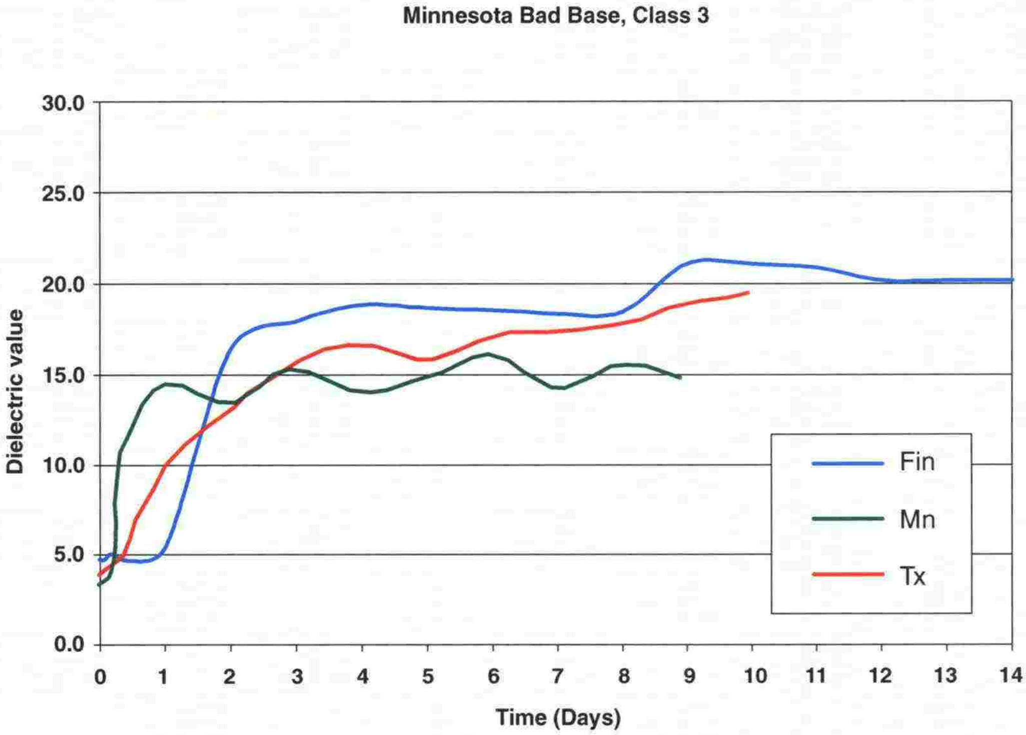

Figure 9. Tube Suction test dielectric profiles from Minnesota bad quality base material

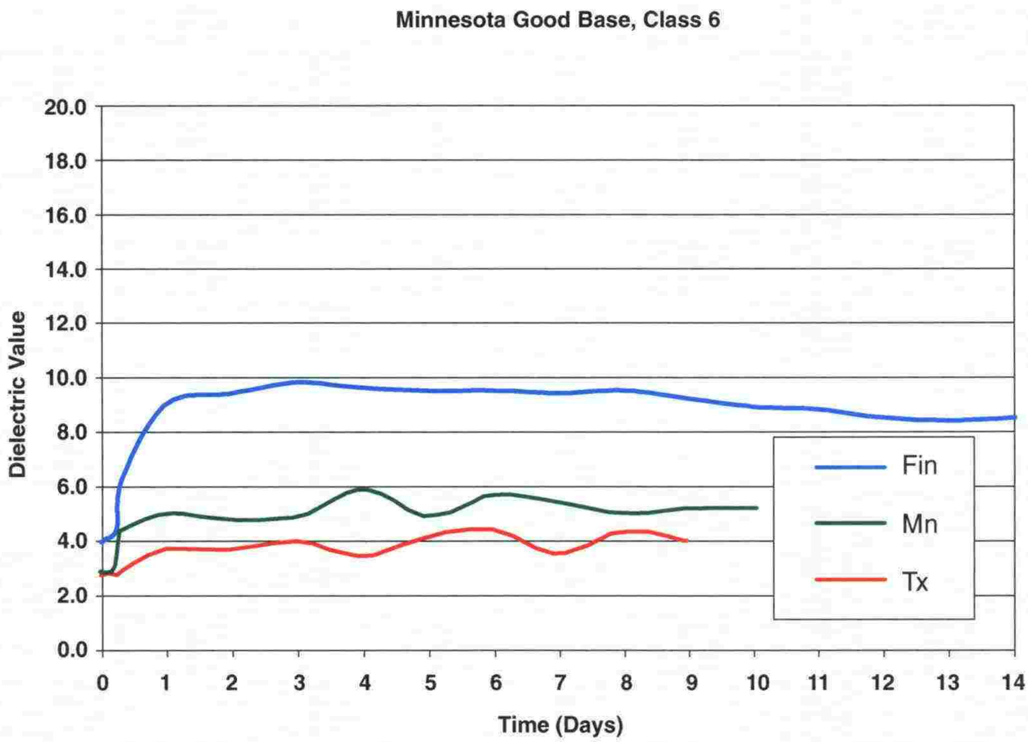

Figure 10. Tube Suction test dielectric profiles from Minnesota good quality base material

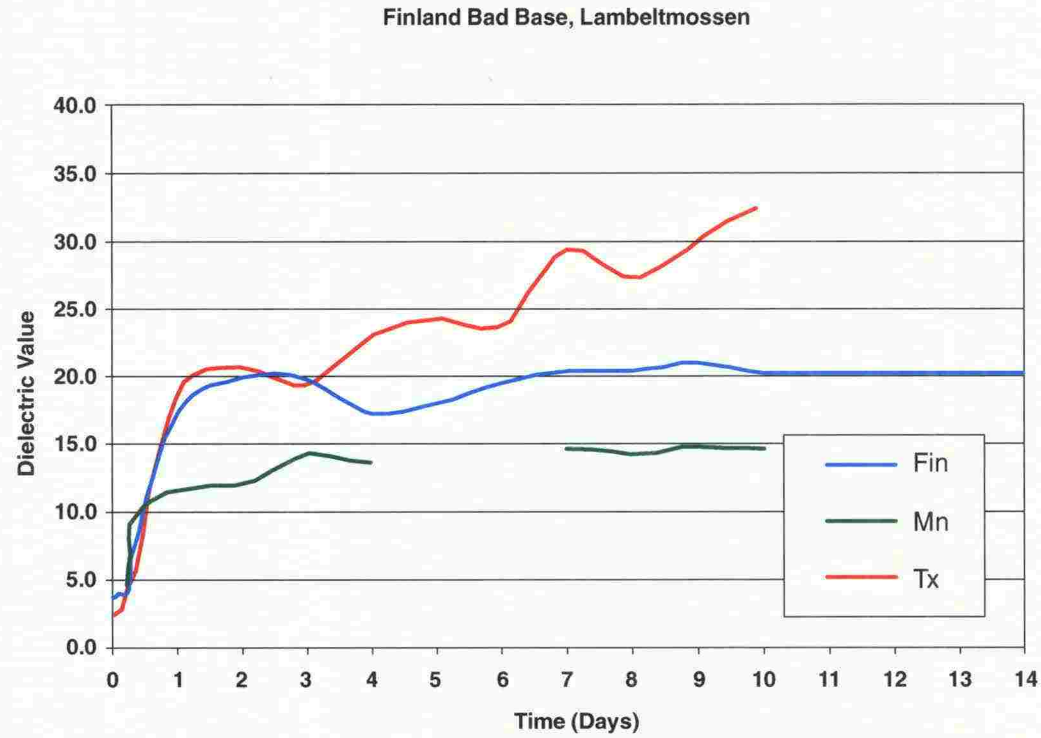

Figure 11. Tube Suction test dielectric profiles from Finland bad quality base material

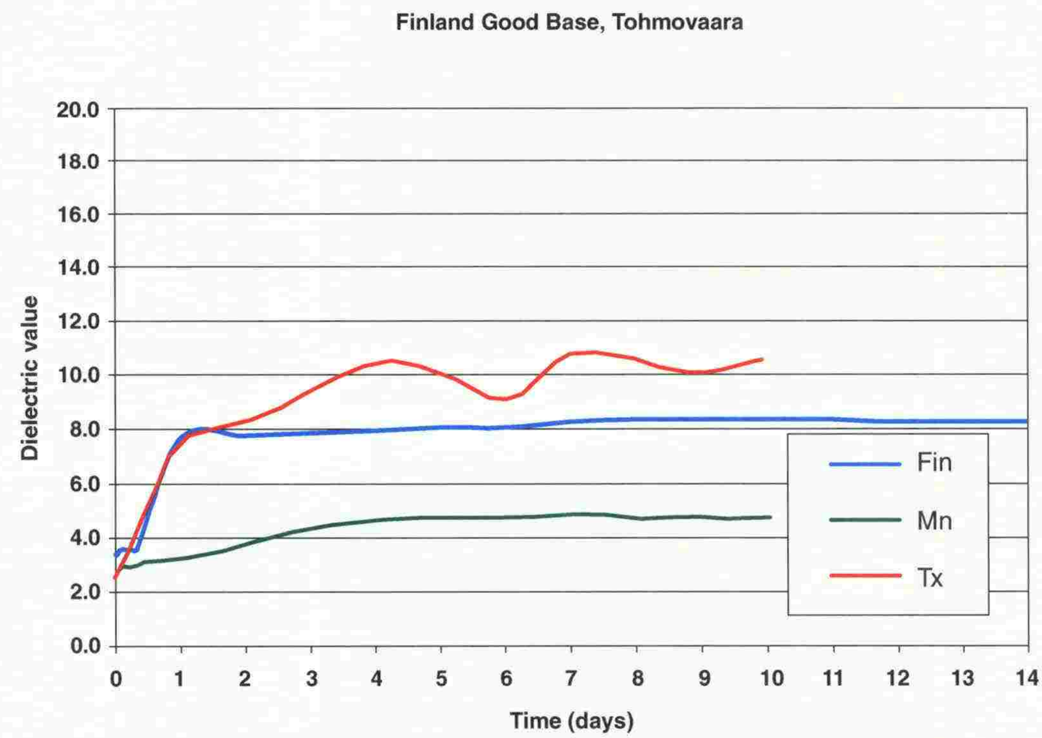

Figure 12. Tube Suction test dielectric profiles from Finland good quality base material

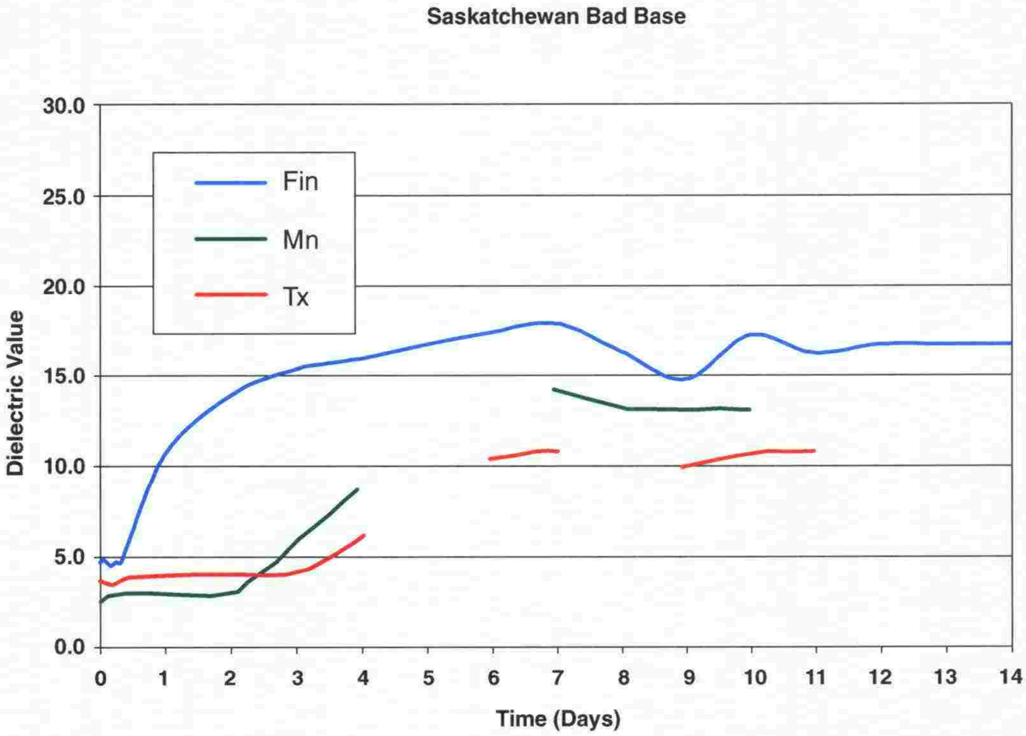

Figure 13. Tube Suction test dielectric profiles from Saskatchewan bad quality base material

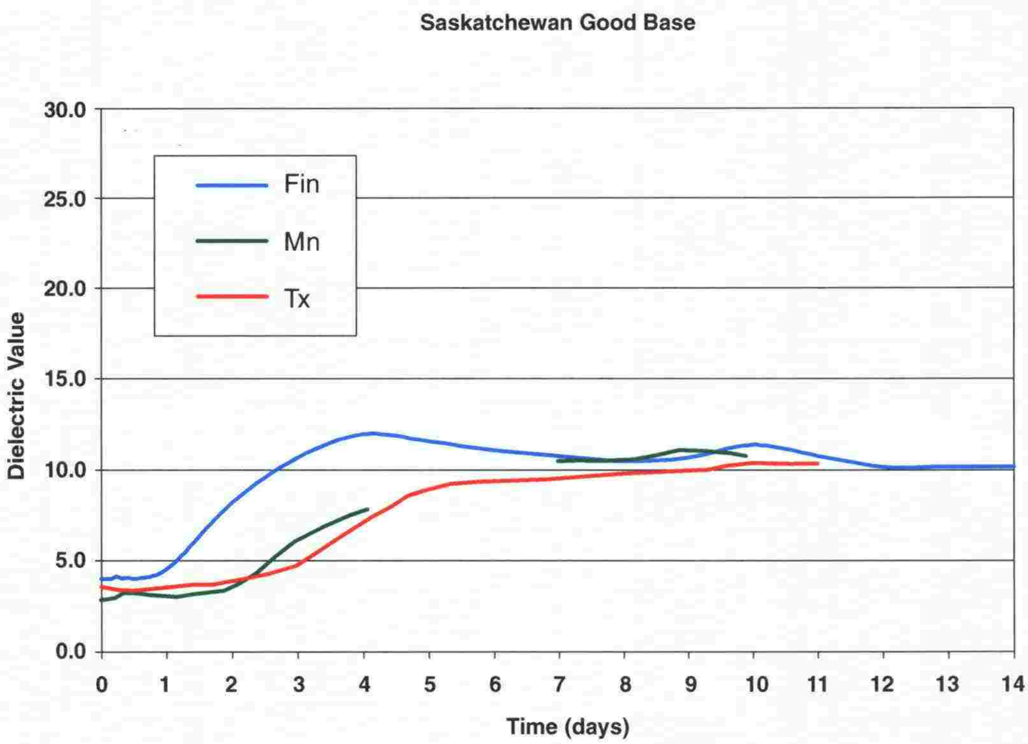

Figure 14. Tube Suction test dielectric profiles from Saskatchewan good quality base material

3.3. COMPARISON OF DIELECTRIC VALUE ASYMPTOTES

Comparison of the dielectric value asymptotes is presented in Table 2. Figure 15 compares the Finnish TST results with the Minnesota and Texas results. Results show that even though there were differences in absolute results in each laboratory, good performers from each country could be identified from the results. The only exception was the result of the Texas aggregates measured in Texas, a likely explanation being that the aggregate samples were not from the same stock piles as the Texas samples sent to Finland and Minnesota. Also the height of the Texas poor quality aggregate sample was higher in test conducted in Texas than in other laboratories (see Appendix 2). The correlation between the results of Finland and Minnesota were good (correlation coefficient: 0.9568), even though the absolute values for the Minnesota results were slightly lower. The correlation between Texas results and the Finnish and Minnesota results was not as good (Fin/Tx: 0.6254, Mn/Tx: 0.7057). The factor was lowered by the results of the Tx aggregates.

Table 2. Dielectric asymptote values of the TST

	Dielectric value		
Sample	Finland	Minnesota	Texas
Texas Bad Base	37	26	27
Texas Good Base	20	15.5	
Minnesota Class 3 (bad)	20	13.7	19.2
Minnesota Class 6 (good)	8.5	3.8	5.4
Finland Bad Base	16.5	14.9	30.5
Finland Good Base	8.4	4.8	10.4
Saskatchewan Bad Base	17	13.3	11
Saskatchewan Good Base	10	10.5	10.1

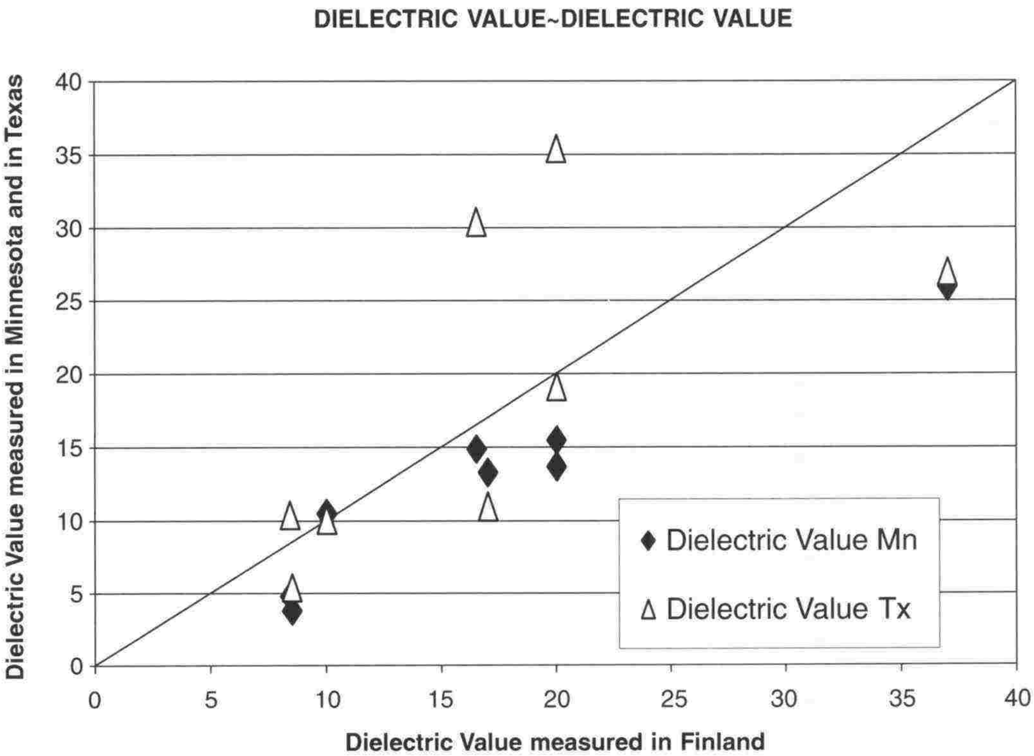

Figure 15. Correlation between Tube Suction test asymptote dielectric value measured in Finland and the corresponding value measured in Texas and in Minnesota.

3.4. MOISTURE CONTENTS OF THE SAMPLES

The results of the moisture content measurements calculated for the samples after the TST are presented in Table 3. Figure 16 compares the results of the Finnish moisture content tests with results taken from similar tests made in Minnesota and in Texas.

Table 3. Moisture contents of the aggregate samples after the TST.

	Moisture (% by weight)		
Sample	Finland	Minnesota	Texas
Texas Bad Base	26.3 ?	10.2	4.5 (?)
Texas Good Base	8.1	5.6	12.0
Minnesota Class 3 (Bad)	8.0	10.3	9.0
Minnesota Class 6 (Good)	5.0	2.9	4.9
Finland Bad Base	8.1	6.5	9.0
Finland Good Base	3.8	3.3	5.6
Saskatchewan Bad Base	5.8		4.6
Saskatchewan Good Base	4.6		3.8

Moisture contents calculated for the Texas aggregates at each laboratory were especially variable. The moisture content of the Texas poor quality aggregate following the test was 26.3 %, 10.2 %, and 4.5 % in Finland, Texas, and Minnesota, respectively. It is obvious that the Finnish results are too high and for this sample Texas laboratory measured only the increase of the moisture content, not the absolute value (see Appendix 2). Texas TST results also show that the moisture content of the Texas good base was greater than the poor base, when the results of the Finnish and Minnesota TST were logical. Figure 16 shows that, if the Texas poor base results are disregarded, Finnish and Texas moisture content results correlate quite well with each other, although the moisture content level in Minnesota is slightly lower after each test.

Figure 17 shows the correlation between dielectric values and moisture contents after individual tests in Finland, Minnesota and Texas. This figure shows that Finnish and Minnesota results have a good correlation between moisture content and dielectric value as well as with each others´ results, but the Texas results show much greater scatter. Results also show that the Finnish results seem to vary in a smaller range compared with the Texas and Minnesota test results. However, it should be noted that the Texas poor quality aggregate results have been disregarded in this comparison.

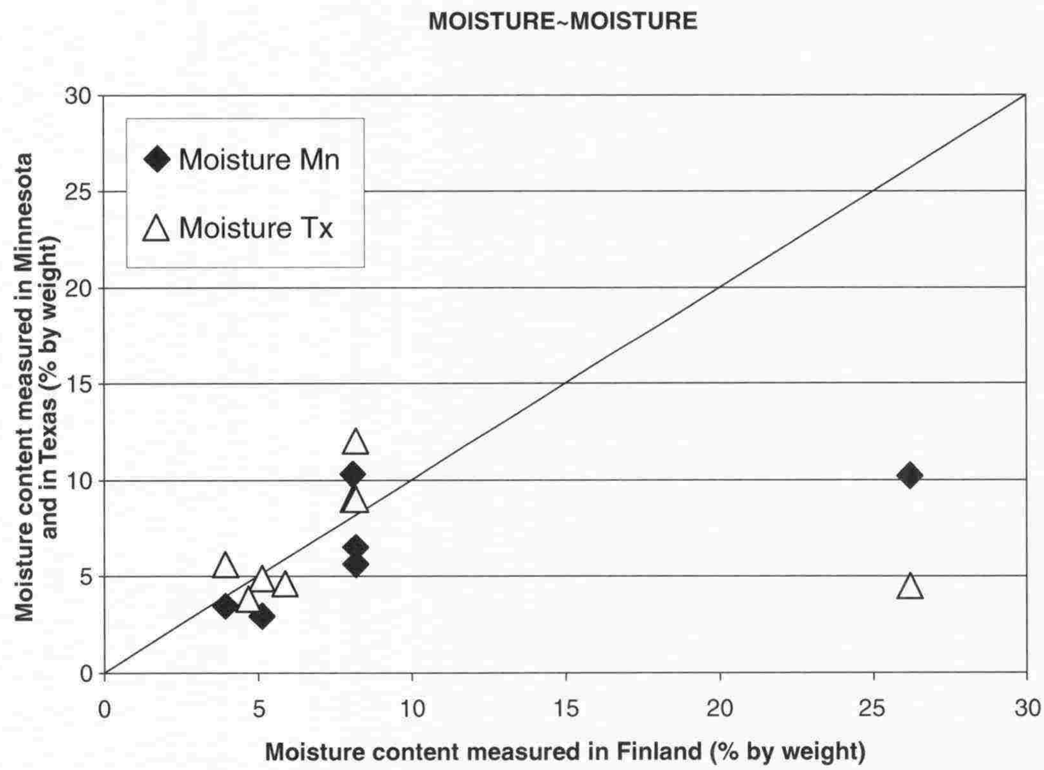

Figure 16. Correlation between moisture content of the samples after the Tube Suction test measured in Finland and the corresponding values measured in Texas and in Minnesota.

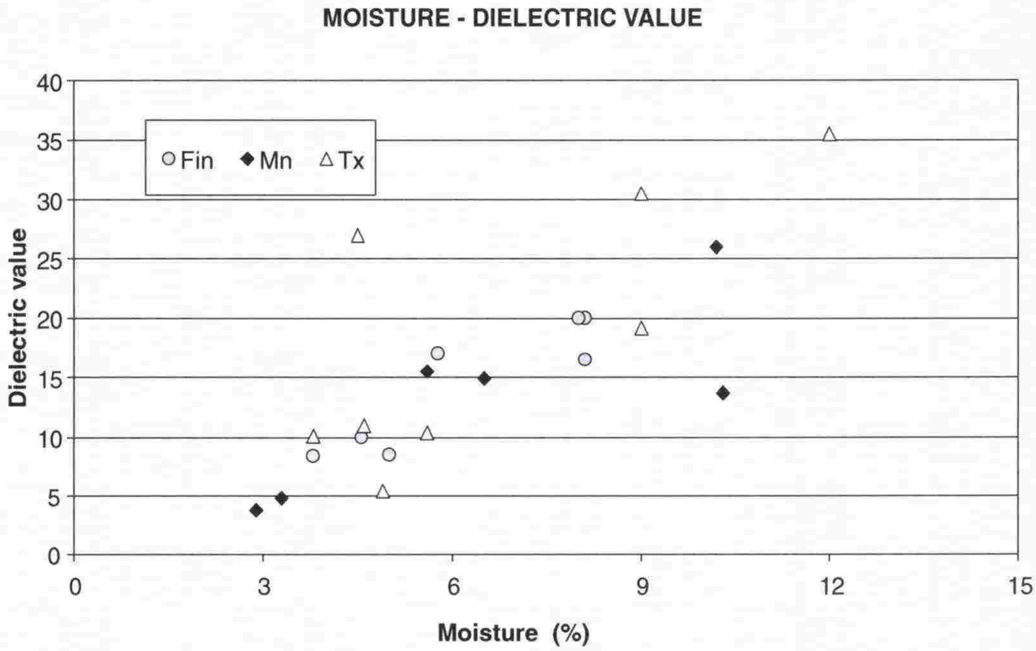

Figure 17. Correlation between moisture content of the materials after the Tube Suction test and the asymptote dielectric value of the corresponding samples.

4. CONCLUSION

The results of the round robin testing proved that despite there being no excellent correlation between the results of all the samples under testing, it was possible to use the results for their original purpose, namely to classify the good, marginal and poor base aggregates. Good bases were shown to be good in every laboratory test and bad ones were shown to be poor. The following conclusions could be drawn from the test results:

- The compaction method used in Finland slightly over-compacts the base material and the settings of the gyratory compactor should be adjusted to more closely correspond to the compaction level reached with a modified Proctor drop hammer method.

- In Finland the TST lasted for 14 days, and at least with these test materials there was no significant change after the tenth day. Therefore, it is worth considering shortening the test period, as results would be reached quicker and the test costs be reduced.

- The dielectric values in Minnesota TST rose slower and generally remained lower compared with other laboratory values. The work team discussed the reason on several occasions, but could not find a clear explanation for that. One possible explanation is that the holes in the plastic tubes were blocked during the compaction and thus were almost impermeable to water. One Texas experiment from the Texas small scale tests (Spencer Guthrie, oral information) suggested that the asymptotic dielectric values may be reached three days faster if the holes are larger. The "soft" mode used in the Percometer measurements also partly explains the lower values, but not the slower rise of the values.

- Statistical comparisons revealed that some of the dielectric measurements in the Texas results were too high. This is likely to be due to the fact that too many fines were added to the surface of the samples, thus distorting the results. Tests performed in Finland in 1999 also proved that using < 2 mm material to smooth a sample surface distorts the results, thus suggesting that this practice should be abandoned. One more potential reason for the slightly higher TST results in Texas is that the tap water used for the sample compaction contains relatively large amount of salt and this might increase the osmotic suction and thus the total suction of the samples.

- It was revealed in discussions that even access of deionised or distilled water must be ensured throughout the test so that the base of the sample does not dry out.

- Because of the above mentioned reasons, the TST results of the round robin tests were not identical, but this does not mean that the test is not repeatable. Spencer Guthrie (Guthrie et al. 2000) has performed in 1999 a series of repeatability testing on three aggregates, and the results of these tests (Figures 18, 19 and 20) showed that if the sample preparation is consistent the results will be quite alike.

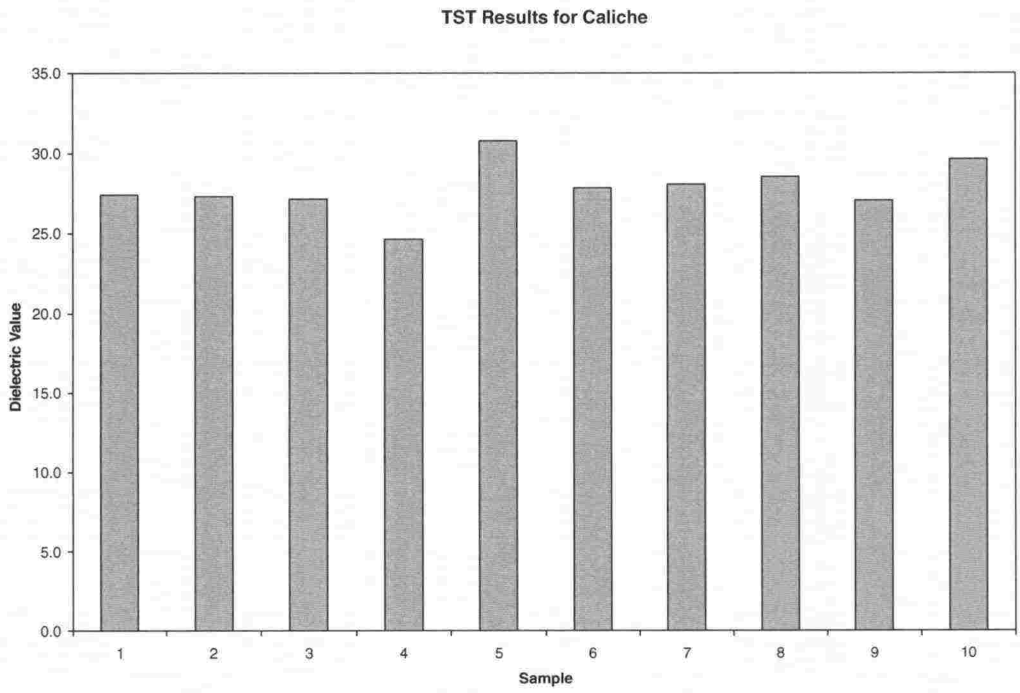

Figure 18. TST repeatability results of Caliche base made in TTI (Guthrie et al. 2000).

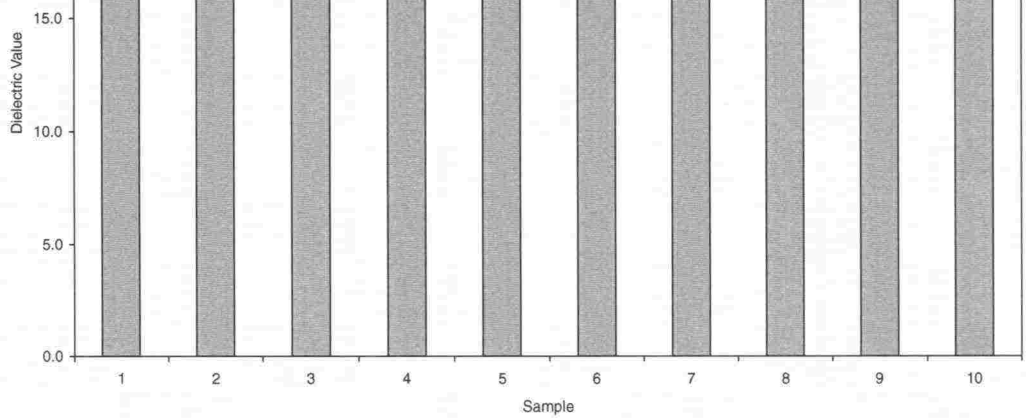

Figure 19. TST repeatability results of Limestone base made in TTI (Guthrie et al. 2000).

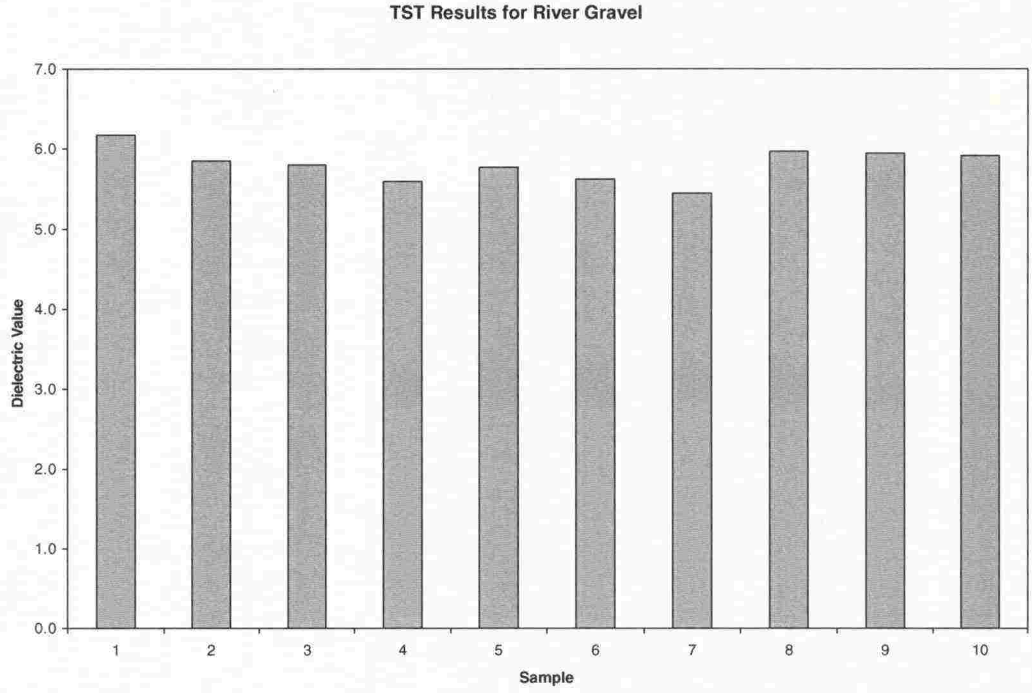

Figure 20. TST repeatability results of River Gravel base made in TTI (Guthrie et al. 2000).

5. FUTURE RECOMMENDATIONS

Future recommendations for changes to the TST protocol are as follows:

1. A compaction method should be applied to get as close to the modified Proctor optimum densities as possible. Additional material for smoothing the surface should only be used in compelling cases, when it is impossible to take measurements from the uneven surface. In these cases the material grain size should be < 4 mm. If the tap water in the laboratory contains high amounts of chlorides and the electrical conductivity of the water measured with Percometer is more than 200 µS/cm it should not be used for the sample compaction.

2. After compaction, the holes in the plastic tube should be cleaned using a fine needle or the end of a piece of stiff wire, in order to allow good contact between the water and the sample. The recommended size of the holes is 2 mm.

3. During the test the tube should be covered with a rubber plate or similar material, in order to minimize the effects of variation in room temperature and air pressure, as well as to protect the sample from any splashes.

4. Measurement time should be 10 days. Times exceeding this should only be used in cases where the dielectric value of the sample is still clearly rising during the last 3 days.

5. It is not necessary to weigh the sample after every dielectric measurement, but weights should be measured in the beginning and at the end of the test. After the test it is recommended to measure the moisture content of the top 50 mm and the moisture content of the whole sample.

6. In addition to measuring the dielectric value, the sample's electrical conductivity should also be measured and analysed, in order to evaluate how much of the total suction value is due to osmotic suction and how much matric suction affects the suction value.

7. When measuring the dielectric values with a Percometer and surface probe, the "hard" mode and multipoint measurement protocol should always be used. When taking the measurements, the probe should be pressed tightly against the sample. The contact pressure should be about 2.5 kg, which can be evaluated using a weighing scale.

8. If the TST results are very close to the limit of rejection, the test may be repeated. If the new result also exceeds the permitted limit, this result should be considered final.

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APPENDIX 1. YLITAPIO

THE PROCEDURE OF TUBE SUCTION TEST

1. The sample preparation and the measurement instructions of unbound Tube Suction Test samples

1.1. Samples

- at least 20 kilos of sample is needed for the Tube Suction Test and the other studies (grading, moisture, etc.)
- the maxim grain size is 25 mm
- the weight of dry material for one tube sample is about 8-9 kg

1.2. The compaction of samples

- the sample is compacted with a Gyratory Compactor into a plastic tube (240 x 152 mm)
- the sample is compacted in an optimum moisture content, which is determined either statistically or experimentally
- the sample is precompacted into the plastic tube in layers
- the height of the compacted sample has to be between 180 - 200 mm, which is reached with different weights of the samples
- Gyratory Compactor has to be calibrated following the next setup:
    - gauge pressure 6.0 bar
    - deflecting angle 2° 17"
    - the tangent of deflecting angle 4%
    - the amount of revs per minute 32
    - the wet weight of the sample has to be entered into the computer
- Gyratory Compactor form is printed after the compaction

1.3. The treatment of tube sample after compaction

- a cover with holes is placed on the bottom of the compacted sample
- the compacted sample is numbered and placed in a 45 °C oven for drying
- the sample is daily weighed after 3 days until the weight do not change, the results are written down
- after the last weighing, the sample is allowed to cool down for at least 2 days at room temperature (20°C) before the actual Tube Suction Test
- the dates, the weight, etc. are written down on the TST-form

1.4. Tube Suction Test

- the first surface dielectric and electrical conductivity measurements are taken using Percometer (multipoint mode) before placing the sample in water bath containing 10-20 mm of de-ionized or distilled water
- during the test it has to be ensured that water level remains close to 10-20 mm
- on the first day the surface dielectric and electrical conductivity measurements are carried out at the intervals of 0, 30, 120, 240, 360, 480 minutes
- after the first day the measurements are taken once a day (in the morning)
- the measurements are repeated every day until the weight and the dielectric value will not rise for three consecutive days
- for each measurement 6 dielectric and 6 electrical conductivity readings are taken on the surface of each sample
- for each set of readings the highest and the lowest value are left out and the average of the remaining four is calculated by Percometer
- the sample is weighed after each measurement
- after the TS-test the grading, the surface moisture content (5cm), the hole moisture content and the specific density are determined
- from the results of the TS-test parameters are calculated by using the computer (asymptotic value of the dielectric, tangent value of the dielectric)

2. Compaction

The compaction of tube samples in the optimum moisture content by using Gyratory Compactor

The optimum moisture content is determined either
a) statistically or
b) experimentally

Some tables have been developed to define the optimum moisture content of the materials. These values are only estimates, because there are many factors that have an effect on the optimum moisture content (for example the grading and the amount of fine aggregate). The actual optimum moisture content is always determined case-by-case.

Experimentally the optimum moisture content of the base material is determined by using the standard or modified Proctor procedure.

On behalf of the TS-test the statistical and the experiential estimate of the optimum moisture content is the cheapest and the most suitable. If the material has higher fines content the optimum moisture content is also higher than normally.

The typical optimum moisture contents of soil types

Soil type	Proctor-density [kN/m^3]	Optimum moisture content [%]
Gravel	20-22	5-7
Sand	16-20	10-18
Silt	15-18	15-25
Clay	14-17	20-30
Clacial Moraine	18-22	6-12

3. Sample height

The height of the compacted sample has to be 180-200 mm, so that the samples are homogendus.

In order to reach the right height of the sample, the compaction properties of material have to be known. In general, the coarse aggregate compacts much less than the aggregate with high fines.

The previous results of the Gyratory Compacter have shown, that the average compaction for base materials is about 10-20 mm. That helps us to evaluate the needed amount of material.

The height of the tube is about 240 mm, so the height of the precompacted sample should be about 20 mm less than the height of the tube.

The precompaction should be made with Proctor hammer.

APPENDIX 2. GUTHRIE AND SCULLION

TEXAS RESULTS FOR ROUND ROBIN TUBE SUCTION TESTING

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INTRODUCTION

This report will describe in detail the Tube Suction Test (TST) procedures utilized at the Texas Transportation Institute (TTI) during round robin testing performed in cooperation with the Finnish National Road Administration, the Minnesota Department of Transportation, and Saskatchewan Highways and Transportation. Each agency sent all other agencies samples of a good and a poor quality base material located in their area. The TST was completed on every sample by all agencies except for Saskatchewan Highways and Transportation.

The topics of aggregate preparation, compaction method, sample drying, mold preparation, sample testing, data collection, and test results specific to the testing conducted at TTI are addressed in this report. Separate data analysis reports for each aggregate base material are also provided for reference. These reports give specific information pertaining to individual sample preparation and testing. A report describing sieve analyses follows
at the end.

AGGREGATE PREPARATION

Aggregate preparation generally included drying, scalping, and mixing at optimum moisture, with noted exceptions. Each aggregate sample was visually inspected upon receipt. Any samples that appeared to contain very coarse materials were sieved through the 1-1/2-inch sieve screen, and all material retained on the screen was discarded. Because of the limited supply of each aggregate sample, optimum-moisture tests were not performed on the Finland, Minnesota, or Saskatchewan samples. Because of their apparent close proximity to optimum moisture, the Minnesota base materials were compacted "as-is" upon arrival. Optimum moistures of 5.3 percent and 3.0 percent were estimated for the Finland Lampeltmossen and Tohmovaara base materials, respectively, by incrementally adding water and mixing in the laboratory to a desired consistency before compaction. Optimum moistures of 5.9 percent and 6.0 percent were likewise estimated for the Saskatchewan good and poor quality aggregates, respectively.

COMPACTION METHOD

After preparation, the aggregate samples were compacted in plastic cylindrical molds of 6-inch diameter and 12-inch height. All samples were compacted in four lifts with a mechanically driven 10-lb drop hammer. Each drop was from a height of 18 inch, and the thickness of each compacted lift was about 2 inch. The final height of each sample was approximately 8 inch.

Except in the preparation of the Saskatchewan base materials and the Texas poor quality base material, each lift of each sample was compacted with 30 hammer blows. This number was increased to 50 for the Saskatchewan samples when a steel sleeve was used around the mold for reinforcement against failure of the plastic cylindrical wall. The Texas poor quality aggregate was also compacted at 50 blows per lift, but its target height was 12 inch. Some fines were added to the surfaces of all but the Saskatchewan samples, and the surface of each sample was smoothed by manually pressing a 4-in-diameter metal disk on the top of each sample in several places as needed.

SAMPLE DRYING

Following compaction, each sample was dried in a computer-controlled environment chamber at 75 percent relative humidity and 104 (F. The samples were left in the chamber until reaching constant weight, often as along as 20 days. The shortest time needed by any sample to achieve constant weight was 13 days.

MOLD PREPARATION

Before any sample was submitted to soaking, 39 holes of 1/16-inch diameter were drilled with equal spacing around the circumference of the mold at approximately 1/4 inch from the outside bottom of the cylinder. This equates to a spacing of about 1/2 inch between holes. Also of 1/16-inch diameter, four holes were drilled in the bottom of the mold, equally spaced around the circumference of an imaginary circle of 4-inch diameter centered on the bottom of the cylinder. Except for the preparation of the Saskatchewan samples, all molds were drilled after compaction of the base material inside them. For the Saskatchewan samples, the molds were predrilled.

SAMPLE TESTING

Following mold drilling as necessary, the samples were placed in a 3-inch deep container for testing at room temperature. As many as ten samples could be placed in the container with sufficient clearance in the center of the group for transport of each sample in and out of the bath for dielectric and weight measurements. Because no sample was ever lifted more than approximately 4 inch above the bottom of the container, water contamination of any sample surfaces was entirely prevented. No mold caps were used. Distilled water of 1/2-inch depth was used in the water bath for sample soaking. The water level was monitored daily, and more was added when needed.

DATA COLLECTION

The analog version of the Adek Percometer™ was utilized in dielectric testing, equipped with a probe of 1-7/8-inch diameter. The "hard" mode was always used. An average force of between 11 and 15 lbs was applied to the probe for each measurement. Where any sample surface was uneven, a few twists of the probe were allowed to ensure adequate probe contact with the sample.

Five dielectric measurements were taken at equal spacings around the perimeter of each sample surface, and one measurement was taken in the center. Weight measurements were also recorded at the time intervals shown on the accompanying data analysis reports. Of the six dielectric readings, the highest and lowest were dropped, and the remaining four were averaged for plotting against time. Except for early removal of the Texas good quality base material from the test for investigation when the dielectric measurements climbed over 30, every sample was submitted to approximately 10 days of soaking and data collection. For samples that did not appear to have reached equilibrium, data was taken for additional days to better establish trends in the dielectric measurements.

At the conclusion of each test, all but the Texas poor quality base material were placed, still in their molds, in an oven at 200 °F for absolute moisture content calculations and subsequent sieve analyses. The results of the sieve analyses are given at the end of this report. All samples are included except for the Texas poor quality aggregate, which was submitted to dielectric testing over two years ago. Electrical conductivity measurements were not taken on any sample except the Texas poor quality base material, which reached a recorded maximum of 250µs/cm.

TEST RESULTS

Compiled from the data analysis reports included with this report, the following Table 1 gives a summary of TST results for each sample. The dielectric values and moisture contents shown for the Finland and Minnesota samples and the Texas poor quality base material were measured after 220 hours of soaking. The dielectric values and moisture contents for the Saskatchewan samples were measured after 259 hours of soaking. The Texas good quality aggregate was terminated at a soaking time of 148 hours.

TABLE 1 Test Results

Aggregate	**Dry Density (lb/ft^3)**	**Moisture (%)**	**Dielectric Value**
Finland Tohmovaara	127.1	5.6	10.4
Finland Lampeltmossen	123.5	9.0	30.5
Minnesota Class 6	108.7	4.9	5.4
Minnesota Class 3	116.7	9.0	19.2
Saskatchewan Good	139.1	3.8	10.1
Saskatchewan Poor	141.6	4.6	11.0
Texas Good	123.1	12.0	35.5
Texas Poor	NA	4.5	27.0

The moisture content shown for the Texas poor quality aggregate is not the absolute moisture content, but reflects the amount of water ingress that occurred after testing began. The moisture contents for all other samples are absolute measurements.

DISCUSSION

Several observations noted during testing are provided here in the interest of evaluating and further refining current TST procedures. These comments are limited to the topics of compaction method, sample drying, mold preparation, and data collection.

COMPACTION METHOD

With regard to the addition of fines at the sample surface, the only aggregate to produce unusual results in actual testing was the Texas good quality base material. The upper 1 in was primarily fines, which softened during testing to the extent that deep footprints were left by the probe where other sample surfaces remained intact. Because the dielectric probe is reportedly sensitive to a depth of about 1 in, the gradation and moisture within that range directly control the measured surface dielectric value. In subsequent testing at TTI, the addition of fines across the whole surface of any sample has been entirely avoided in order to keep the sample as homogeneous as possible.

SAMPLE DRYING

During these round robin tests, each sample was dried at 104 (F and 75 percent relative humidity until achieving a constant weight. This drying process often required as long as three weeks, and, even after equilibrium has been reached, it has been found by further testing that as much as 4 percent water can remain in a given sample under these conditions. Though three weeks may be required for the sample to reach equilibrium, successful testing has been accomplished at TTI with a drying time of only three days. It is therefore proposed that shorter drying times be evaluated for standardization in the final TST protocol.

MOLD PREPARATION

TTI further recommends that an analysis be performed on the sensitivity of the TST results to the size and number of holes drilled in the mold to facilitate water ingress during soaking. Increasing the total cross-sectional area through which water is allowed to flow might serve to reduce the overall testing time.

DATA COLLECTION

TTI supports the proposal from the Finnish National Road Administration that it is not necessary to weigh each sample every time dielectric measurements are made. However, measurements of the weight before soaking and the weight at the end of soaking should remain mandatory if the increase in water content is to be calculated. TTI experience also suggests that because the dielectric values measured toward the end of the test are most important in assessing moisture susceptibility, the frequency of measurements used in the early hours of the test may be reduced to at most one measurement per day.

SUMMARY

This report focuses strictly on the round robin testing experience at TTI and provides detailed descriptions of the test procedures used. This information is intended for inclusion in a formal comparison of similar data from the other agencies participating in this preliminary evaluation of the TST. As indicated by comments throughout this report, additional research is especially needed to investigate various means of reducing the overall time required for the TST and to determine the sensitivity of TST results to various testing parameters. Furthermore, in order to facilitate worldwide comparisons of TST results, a standardized procedure needs to be developed and implemented. The repeatability and reliability of the test should then also be explored.

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